Precision Studies of Nucleon Structure and Medium Modifications with Neutrino Beams

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The flavor sensitivity of the weak interaction makes neutrino-nucleon scattering a particularly powerful tool for studying the flavor structure of protons and neutrons in terms of the universal parton distribution functions (PDFs). Additionally, measurements of both neutrino and anti-neutrino scattering allows for separations of valence and sea quark distributions. However, the full power of utilizing neutrino scattering from such studies has been hampered by the relatively poor statistics relative to charged lepton scattering data and large neutrino flux uncertainties provided by past experiments, such as bubble chambers filled with liquid hydrogen and deuterium [1]. This is especially true in the region of large Bjorken$-x$, which is dominated by the valence u and d quark distributions.

There does exist relatively high statistics data from neutrino scattering experiments on a number of heavy nuclei, such as Iron [2] and Lead [3]. However, the extraction of nucleon structure, and in particular PDFs, from such data is hampered by the likely existence of large nuclear medium modification effects [4]. Medium modifications to nucleon F_2 structure function have been well measured in charged lepton scattering experiments since the discovery by the EMC [5, 6] collaboration nearly 30 years ago of the suppression of F_2 in heavy targets relative to that in the deuteron for $0.3 < x < 0.7$. There currently exists little experimental information on medium modifications in neutrino scattering.

Future neutrino scattering experiments with an intense and well understood flux could address a number of fundamental questions concerning nucleon structure. First, a hydrogen target could provide a clean and precise determination of the proton d/u ratio at large x. Such measurements would be complementary to expected results from proposed measurements at Jefferson Lab [7–9], but would be free of the assumption of charge-symmetry in the quark distributions (eg. $d_p = u_n$).

Second, a deuterium target combined with heavy nuclear targets in the same experiment could be utilized to study medium modification effects comparable with those from charged lepton scattering. This could provide a crucial clue into the origin of the EMC-effect, for which there is still no theoretical consensus.

Third, by comparing neutrino to anti-neutrino data on a deuterium target one could look for evidence of charge-symmetry violations (CSVs) at the quark level. If found, these would help provide an explanation for the NuTeV anomaly [10].

A Letter of Intent to propose filling the existing MINERνA cryogenic target with 2300 liters of liquid deuterium during the NOνA era to address the latter two fundamental physics questions has already been considered by the Fermilab PAC, and engineering investigations are ongoing in regards to the safety of both running the target underground and the recovery and storage of deuterium. If fully approved, these measurements would provide major contributions to the study of nucleon structure and medium modifications. Such measurements could be improved still further by running the NuMI beamline in a high energy configuration with a peak energy of 14 GeV. Monte Carlos studies have shown that even a year running for each of neutrino and anti-neutrino modes in this configuration would yield up to an order of magnitude more statistics for the studies discussed here.

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